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Meta title: Outdoor Energy Storage PCS Transformer & PFC Inductor Design Guide | ProMagTech

Meta description: Reliability of outdoor energy-storage PCS magnetics is governed by thermal cycling, potting CTE match, sealed-enclosure heat, cold-start and partial discharge — not heat alone. Includes indoor vs outdoor comparison, potting & material selection tables, core material comparison, a 7-item specification checklist and FAQ.

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TECHNICAL GUIDE / OUTDOOR ENERGY STORAGE PCS MAGNETICS

Outdoor Energy Storage PCS Transformer & PFC Inductor Design Guide

Thermal cycling, potting match, sealed-enclosure heat, cold-start and partial-discharge control

1. Core Conclusion

In an outdoor energy-storage PCS (PV/battery DC input → PFC boost → DC/AC inverter → AC output), the reliability of the transformer and inductor is not governed by absolute temperature alone. It is governed by five dimensions of equal importance:

- Key takeaway:** 1. Thermal cycling: repeated daily and seasonal temperature swings are the primary failure driver outdoors — not peak temperature.
2. Potting CTE match: a mismatch between potting compound and copper/core expansion shears interfaces apart under cycling, turning 'protection' into a failure source.
3. Sealed-enclosure heat: IP65 sealing conflicts directly with cooling; hot-spot runs far above an open bench, halving insulation life per Arrhenius.
4. Cold-start: at the -40°C end, permeability drift, material embrittlement and cold inrush are more destructive than the hot end.
5. Partial discharge & inductance: PD erodes insulation under continuous DC and is a first-class metric alongside inductance and temperature rise.

The sections below give the working-condition comparison, design requirements, material selection, a mandatory specification checklist and FAQs. All figures are public industry standard ranges or typical engineering reference values, to be confirmed per project.

2. Background & Indoor vs Outdoor: 7-Factor Comparison

Outdoor storage systems sit in sealed, non-air-conditioned cabinets exposed to diurnal swing, seasonal cycling, condensation, salt fog, vibration and altitude. The magnetics (HF transformer for isolation and voltage matching; PFC inductor for boost and current shaping) face conditions that differ systematically from indoor/data-room storage:

Table 2-1 Indoor vs Outdoor storage magnetics — 7-factor comparison

Factor	Indoor / room	Outdoor storage	Design implication
Ambient range	~5–40°C, controlled	-40°C to +85°C (custom)	Full-range design; cold-end margin critical
Diurnal swing	Small (<10°C)	Large (30–50°C common)	Cycling drives potting/interface fatigue
Cooling	Ventilated, moving air	IP65 sealed, near-still air	Hot-spot elevated; life derated (Arrhenius)
Condensation	Controlled, none	Daily condensation, moisture	Potting/seal must block ingress + PD
Corrosion/salt fog	Low	High in coastal/industrial	Lead, terminal, housing corrosion protection
Vibration	Low	Transport + wind + equipment	Winding fixity, potting vibration resistance
Maintainability	High, replaceable	Low, dispersed sites	Far higher reliability / maintenance-free

Note: Five of the seven factors (swing, cooling, condensation, corrosion, maintenance) are essentially non-constraints indoors but all apply outdoors simultaneously. This is the fundamental reason outdoor magnetics cannot reuse indoor selection.

3. Key Design Requirements: Potting/Sealing Comparison & 6 Control Measures

The core of outdoor magnetics design is balancing sealed protection against cooling and cycling-fatigue resistance. The table compares common potting/sealing schemes:

Table 3-1 Outdoor potting/sealing scheme comparison (5 options)

Scheme	Moisture/IP	Cooling	Cycling resistance	Use & caution
Full rigid epoxy	High (IP65+)	Good (filled)	Depends on CTE match	Use low-stress / elastomer-modified compound
Semi / partial potting	Medium	Good	Better (stress relief)	Weaker moisture barrier; needs sealed housing
VPI impregnation	Medium	Good	Good	Mainly insulation/vibration, not main waterproof
Potting + elastic buffer	High	Good	Excellent (buffers CTE)	Higher cost; preferred for high reliability
Sealed housing only	High (housing IP)	Poor (air insulates)	Good	High hot-spot; low-power / low-rise parts only

On top of the scheme, outdoor reliability requires these 6 control measures:

6 Reliability Control Measures for Outdoor Storage Magnetics

- ▶ **Potting CTE match** — Select compound with CTE close to copper/core, or elastomer-modified, to reduce interfacial shear
- ▶ **Thermal-shock validation** — Run hundreds of -40↔+85°C thermal cycles / shocks, not just a room-temperature bench
- ▶ **Sealed hot-spot test** — Measure hot-spot inside the sealed enclosure at full load and high ambient, not on an open bench
- ▶ **Cold-start program** — Verify inductance, material toughness and cold inrush stress at the minimum design temperature
- ▶ **Partial-discharge control** — Control inter-layer/turn-to-turn field; verify PD onset under continuous DC, not only hi-pot
- ▶ **Corrosion / conformal** — Lead/terminal corrosion protection, conformal coating or potting coverage for salt fog & condensation

4. Core Material Selection: 4 Materials for Outdoor Use

Common core materials for outdoor PFC inductors and transformers trade off high-frequency loss, DC bias, temperature stability and cost. Comparison of 4 classes (typical public ranges, confirm per grade):

Table 4-1 Core material comparison for outdoor use (4 classes)

Material	Typ. Bs	Curie temp	HF loss	DC bias / temp stab.	Outdoor fit & caution
Fe-Si powder	~1.5–1.6T	High (>700°C)	Medium	Soft sat., good temp stab.	Preferred for high-current PFC; cost-effective
Sendust (FeSiAl)	~1.0–1.05T	High	Lower	Soft sat., low magnetostriction	Lower loss & noise; medium cost

Material	Typ. Bs	Curie temp	HF loss	DC bias / temp stab.	Outdoor fit & caution
High Flux	~1.5T	High	Medium	Strong DC-bias capability	Good for high DC-bias inductors
Ferrite (MnZn)	~0.4–0.5T	~150–250°C	Low (best at HF)	Temp-sensitive, saturates	Preferred for HF transformer; watch hot derating

Selection tip: The outdoor hot end approaches the Curie region of ferrite, requiring high-temperature derating; powder cores (Fe-Si, Sendust, High Flux) have high Curie temperature, soft saturation and good stability, fitting outdoor high-current wide-temperature use. Final choice balances switching frequency, DC bias, temperature rise and cost.

5. Potting & Insulation Material Selection

The non-magnetic materials — potting and insulation system — are often what actually limit life. Comparison of common materials by temperature class, CTE and weatherability (typical public ranges, confirm per grade):

Table 5-1 Potting & insulation material comparison (5 classes)

Material	Temp class	CTE behavior	Weather/humidity	Use & caution
Rigid epoxy	~-40 to +130°C	High CTE, rigid	Excellent moisture	Watch cycling cracking; low-stress formula
Elastomer-mod. epoxy	~-50 to +130°C	Lower CTE, compliant	Excellent	Buffers CTE; preferred high-reliability outdoor
Silicone potting	~-50 to +200°C	Low modulus, wide temp	Excellent	Wide temp, good cycling; slightly lower conductivity
Polyurethane (PU)	~-40 to +100°C	Flexible	Medium	Good low-temp flexibility; high-temp limited
NMN / polyimide film	Class H (180°C)+	Film	Excellent temp	Turn/layer insulation; pair with creepage design

Why flat wire is required above 30A

Outdoor storage PFC inductors often carry tens of amperes. Above roughly 30A, round-wire skin effect, proximity loss and window utilization deteriorate quickly, making flat wire the better or necessary choice:

4 reasons to choose flat wire above 30A

- ▶ **High window utilization** — Edge-wound flat wire packs a high fill factor — more current in the same window, lower DCR
- ▶ **Better heat path** — Large flat contact area to bobbin/core conducts heat out, lowering hot-spot
- ▶ **Controlled HF AC loss** — Properly arranged flat wire reduces proximity loss versus solid round wire
- ▶ **Mechanical stability** — Edge-wound structure is rigid and vibration-resistant — valuable in outdoor vibration

6. 7 Items That Must Be Specified

Before quoting or freezing an outdoor storage magnetics part number, the following 7 items must be explicitly specified. Missing any one means a bench pass cannot represent outdoor reliability:

7 mandatory specification items for outdoor storage magnetics

- ▶ **Full-range conditions** — Minimum cold-start temp, maximum ambient, diurnal swing range
- ▶ **Sealed temperature rise** — Hot-spot rise inside IP65 enclosure at full load and high ambient
- ▶ **Thermal-cycling requirement** — Number and criteria of -40↔+85°C thermal cycles / shocks
- ▶ **Potting & CTE scheme** — Potting grade, CTE-match strategy, presence of elastic buffer layer
- ▶ **Insulation & PD** — Creepage/clearance (per system voltage + pollution degree), PD-onset requirement
- ▶ **Magnetic parameters** — Inductance and its low/high-temp drift, saturation margin under DC bias
- ▶ **Protection & certification** — Corrosion/salt-fog, conformal class, and target-market safety/certifications

7. FAQ

Q1: Why can't outdoor storage magnetics reuse indoor/data-room selection?

Because the working conditions differ systematically (see Table 2-1). Indoor is controlled, ventilated and condensation-free; outdoor faces large swings, sealed cooling, condensation, salt fog and a maintenance-free requirement at once. Magnetics carried over from indoor selection can pass every bench test yet expose outdoor-specific failures in thermal cycling, sealed hot-spot and cold-start.

Q2: For outdoor failures, is heat or cold more dangerous?

Both, by different mechanisms — and cold is often underestimated. The hot end shortens insulation life (Arrhenius) and approaches the ferrite Curie point; the cold end causes permeability drift, embrittlement and cold-start shock. The real killer is usually the repeated cycling between them — the change in temperature, not either extreme alone.

Q3: Is more potting always more reliable?

No. Full potting improves moisture and vibration resistance, but if the compound's CTE does not match copper/core, it will shear interfaces apart under cycling, causing ingress and PD. The reliable approach is a CTE-matched or elastomer-modified compound validated by thermal-shock cycling, rather than maximizing potting volume.

8. Related Resources & Contact

Related technical resources

Topic	Link
AIDC & Energy Storage PCS high-current inductor design	aidc-energy-storage-pcs-high-current-inductor-design
Flat wire vs round wire inductors	flat-wire-vs-round-wire-inductors
Outdoor ESS inductor thermal cycling failure	outdoor-energy-storage-inductor-thermal-cycling

Contact ProMagTech: SHENZHEN PROMAGTECH CO.,LTD. designs custom flat-wire inductors and transformers for outdoor energy-storage PCS, PV-plus-storage and related power-conversion platforms.

Send your outdoor conditions — minimum cold-start temperature, diurnal swing, sealed-enclosure structure, potting scheme, full-load temperature-rise requirement — and we will assess your magnetics' exposure across the five dimensions above.

Web: www.promagtech.com

Disclaimer: All temperature, Bs, Curie point, CTE, cycle-count and insulation-class figures in this guide are public industry ranges or typical engineering reference values, not ratings of any specific product. Final specifications must be confirmed per project by topology, measurement and reliability requirement.

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